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ADP014977

TITLE: Plasma of Free Burning Electric Arc between Composition Electrodes in Air

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This paper is part of the following report:

TITLE: International Conference on Phenomena in Ionized Gases [26th] Held in Greifswald, Germany on 15-20 July 2003. Proceedings, Volume 4

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Plasma of free burning electric arc between composition electrodes in air

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This paper deals with spectroscopy investigations of plasma of free burning electric arcs in air between electrodes from composition materials on the base of cooper (Cu, Cu-W, Cu-Mo, Cu-Mo-LaB$_6$) and silver (Ag, Ag - CdO, Ag – Ni).

1. Introduction

A problem of developing of reliable interrupting devices, where ignition of electric arc often is realised, can not be resolved without careful analysis of processes which take place in the arc and its electrodes. Furthermore, an electric arc, being generated at contact disconnection, results in considerable material erosion of contacts. This causes the decrease of device efficiency and limits reliability of its activity.

In this paper the processes occurred in a free burning electric arc in air between electrodes from composite materials on the base of cooper *(Cu, Cu-W, Cu-Mo, Cu-Mo-LaB$_6$)* and silver *(Ag, Ag - CdO, Ag – Ni)* were studied. Such arc is model of arcs arising between contacts of current disconnectors of electric circuits.

2. Experimental Set-up

The arc was ignited between the end surfaces of the non-cooled electrodes. The discharge gap l_{ak} was of 2, 4, 6 or 8 mm. The diameter of the rod electrodes was of 6 mm. To avoid the metal droplets appearing a pulsing mode was used: the current pulse up to 30 A was put on the "duty" weak-current (3.5 A) discharge. The pulse duration ranged up to 30 ms. The quasi-steady mode was investigated.

Because of the discharge spatial and temporal instability the method of the single tomographic recording of the spectral line emission was used. A 3000-pixel CCD linear image sensor (B/W) Sony ILX526A accomplished fast scanning of spatial distributions of radiation intensity. It allows the recording of the radial distributions of nonstationary arc radiation intensity in arbitrary spatial sections simultaneously.

Just as previously spectrometer [1-2], the using of the monochromator with the significant astigmatism allowed excluding additional focusing optics from the optical path of given spectrometer. The CCD linear image sensor is directly aligned with sagittal focal plane of monochromator behind its exit slit. This slit is located in the meridional focal plane. Such technical decision enables to increase aperture ratio of the device and to register spatial distribution of radiation intensities along an entrance spectral slit of monochromator in a given spectral range. The observed spatial distributions of spectral line intensities can be approximated by Gaussian function and transformed into local distribution by Abel inversion. Our developed software provides such procedure on the base of Bockasten technique [3].

The synchronisation of operation of the CCD linear image sensor with the external electrical circuit is stipulated. The ISA interface slot of IBM PC in a control and data exchange is used.

In a combination with a Fabry-Perot interferometer (FPI) the spectrometer provides simultaneous registration of spatial and spectral distribution of radiation intensities. Thus, the spectrometer allows measuring contours of spectral lines in different spatial points of plasma volume.

3. Results and Discussions

3.1 Electric arc between electrodes from composition materials on the base of cooper *(Cu, Cu-W, Cu-Mo, Cu-Mo-LaB$_6$)*

The radial profiles of temperature are determined in the average cross section of the discharge gap l_{ak} = 2, 4, 6 and 8 mm in air at arc currents 3.5 and 30 A. The temperature profiles are obtained from relative intensities of copper spectral lines 510.5 and 521.8 nm. Because of the discharge spatial and temporal instability the statistical treatment of obtained data was carried out. The spectral sensitivity of the experimental set-up was taken into account.

As recently was found the some secondary structure on a surface of electrodes can be realised during the discharge operation [4]. Therefore we studied our plasma in a two different modes. In the first mode the measurements of radial distributions of spectral line intensities were carried out as a statistical average value during the series of current pulses (30A) putted on the "duty" weak-current discharge (3.5 A). In this case the secondary structure on a surface of electrodes was realised. To avoid the influence of such secondary structure during the discharge operation in an another mode we measured the radial distribution of spectral line intensities as a statistical average value of single current pulses of an electric arc between smoothed surface of electrodes.

The radial temperature profiles of the arc between Cu-Mo-LaB_6 electrodes in two different modes are measured. In the first mode of the arc operation we investigated plasma of the discharge between smoothed surface of electrodes. The next mode corresponds to the case of electrode surfaces covered by a secondary structure, which is realised under the arc activity.

From the comparison of obtained results the key role of the condition of the surface electrode follows. Really the presence of the secondary structure must decrease the erosion of the electrode material. As a result the amount of lightly ionised metal vapours in a discharge gap must be decreased. Therefore at the same arc currents the temperature in plasma column must be higher in case of secondary structure on a surface of electrodes.

It was interesting to compare the influence of composition of the electrodes on the plasma parameters. Additionally investigations of radial profiles of temperature in the arc discharge between pure copper electrodes were carried out. We carried out the similar investigations of plasma of electric arc between Cu-Mo and Cu-W electrodes in the first mode of the arc operation as well.

We can compare obtained radial temperature profiles of the arcs between Cu-Mo-LaB_6 electrode surfaces with a secondary structure and between copper electrodes. From these results follows that in arcs with discharge gaps 4, 6 and 8 mm at the arc current 30 A the axial temperatures are higher in case of Cu-Mo-LaB_6 electrodes. This phenomenon can be cased by both the additions of the Mo-LaB_6 to copper in such composition and a secondary structure of electrode surfaces. In case of discharge gap 2 mm such behaviour of axial temperatures are not observed. It is natural because the plasma of such arc probably is not in a local thermodynamic equilibrium. Such effect was observed in plasma of a short free-burning electric arc between copper electrodes [5].

The increasing of both the temperature and the efficiency of the plasma torch as a tool in the electrical erosion cutting is probably one of the factors, which determine the productivity of the dimensional treatment in the presence of the boron-containing compounds.

We compared radial temperature profiles of the arc between Cu, Cu-Mo, Cu-Mo-LaB_6 and Cu-W electrodes also. The arcs between composition electrode surfaces with a secondary structure were investigated in this case. The essential influence of the additions to the electrode materials on the arc plasma temperature is found [6].

3.2 Electric arc between electrodes from composition materials on the base of silver *(Ag, Ag-CdO, Ag-Ni)*

As the width of the spectral line AgI 466,8 nm is determined by the quadratic Stark effect, i.e. the width of the spectral line is proportional to the electron density N_e in the discharge, the variation of its value means the variation of this plasma parameters.

It was found that the width of the spectral line in a case of the pure silver electrodes is comparable with the FPI instrumental contour (free spectral range of the FPI $\Delta\lambda$ = 0.36 nm). The width of this line increases in an arc between *Ag-Ni* electrodes. It caused by increasing of the electron density in the discharge plasma.

The obtained results are in a good agreement with earlier published [7]. The matter is that in a spark plasma the electron density increases at the using of the composition electrodes made from the pure metals. This effect is especially visible with increasing of their particles dispersity. For instance, in a case of pure copper $N_e/(10^{18}\,cm^{-3}) = 1.48$. In a case of pure tungsten this parameter equals 0.57 and in a case of a composition *Cu-W* it equals 1.92 with an average size of particles $r_{av} = 0.3\ \mu m$.

We also measured the radial profiles of temperature in plasma of the arc between *Ag-CdO*. These profiles are obtained from relative intensities of spectral lines CdI 479.9, 508.5 and 643.8 nm. It is necessary to pay attention to unusual low temperature value (about 4000 K) in such discharge plasma. It can be caused by the significant amount of cadmium vapours in a gap. The matter is that the melting temperature of *Cd* is lowest among metals (~300°C), which are usually used in the production of the composition materials.

4. Conclusions

Based of spatial profiles of the temperature and electron density the model of the investigated plasma can be developed. It is visible from the analysis of the obtained results that the processes occurred in the discharge gap are determined by erosion of the electrode material and condition of its surface.

5. References

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